Building a Piezoelectric Footfall Generator to Investigate its Energy Harvesting Efficiency and Practicability in Hong Kong

Yu Yueming, Fang Xun and Ma Barry Qiyuan

October 2024

Figure 0: Image showing group members and the generator.

Originally produced for the Cambridge International Education Science Competition in October 2024.

Copyright © 2024 Yu Yueming; Fang Xun and Ma Barry Qiyuan. All rights reserved. Uploaded to the Internet Archive (archive.org) under Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International. For queries, email yueming.yu@outlook.com.

Aim: To design and build a prototype of piezoelectric generator and test it locally at school.

Objective: To introduce the usage of piezoelectric generators as a new source of sustainable energy and electricity supply in Hong Kong.

Research Question: Is implementing piezoelectric energy harvesting in Hong Kong practicable?

Background Research

This investigation focused on finding a new sustainable energy source to generate electricity in Hong Kong: energy harvesting with piezoelectric effect.

As one of the world's most prominent megacities, Hong Kong's electricity consumption is substantial. In 2023, Hong Kong consumed 163,558 terajoules of electricity. The cost of electricity in Hong Kong, however, is notably high due to its reliance on imported fossil fuels. After extensive research, we found that Hong Kong is heavily reliant on fossil fuels, with the scale of renewable energy use in the city being less than 1 percent of the electricity, lagging significantly behind other countries with populations like that of Hong Kong.

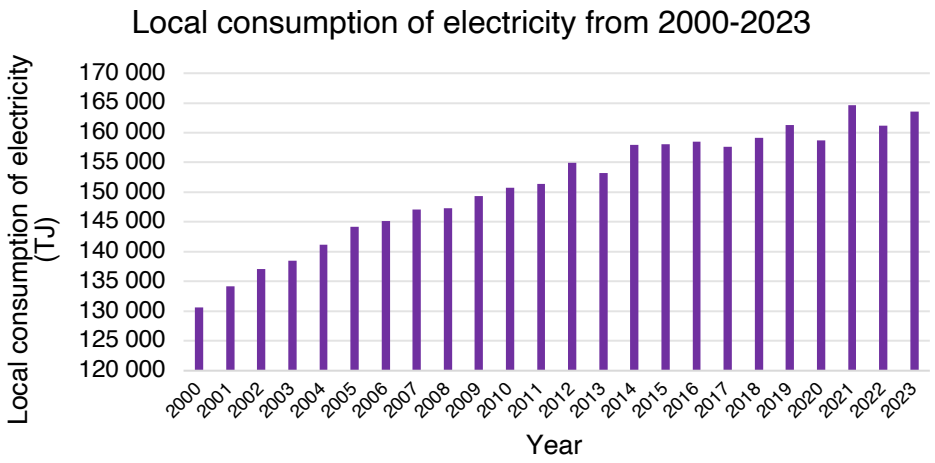

Figure 1: Bar chart representing Hong Kong's yearly total electricity consumption from 2000 to 2023.

As seen in Figure 1, there is a clear upward trend in the use of electricity in Hong Kong, from 130,675 terajoules in the year 2000 to 163,558 terajoules in 2023. With the growing usage of electricity and the city's high reliance on fossil fuels. it is essential to promote the adoption of sustainable energy practices and technologies to meet the growing energy demands while reducing the environmental impact.

However, Hong Kong's dense urban environment precludes large-scale installation of the more common sustainable energy sources. For example, Hong Kong's mountainous geographical characteristics makes it difficult to find large open spaces to install solar panels, while in the urban areas, the solar panels can only be installed on rooftops, and it is made inefficient by the shades cast by the many high-rise buildings and skyscrapers.

Through further research, we found out that Hong Kong is the fourth most densely populated region in the world. As students in Hong Kong, we noticed that many public spaces, such as schools, Mass Transit Railway (MTR) stations, pedestrian tunnels, and malls, experience heavy foot traffic. In 2017, Hong Kong citizens take an average of 6,880 steps a day, making them the most active in the world.

With that amount of people flow, Hong Kong is the optimal location to apply piezoelectric footfall energy harvesting technologies. Energy harvesting is the conversion of energy from the surroundings or external sources into electrical energy for use in small autonomous devices. Piezoelectric generators convert the normally wasted kinetic and vibration energy to usable electrical energy and can capture energy from foot traffic. This technology aligns with international efforts to combat climate change and reduce reliance on fossil fuels, such as the United Nations' Sustainable Development Goal 7, promoting affordable and clean energy. Yet, there remains a lack of widespread adoption of piezoelectric energy, as the energy output of piezoelectric generators is relatively low.

We gathered data to track the pedestrian traffic within our school. The count represents how many times a person traversed our school's third-floor corridor on October 28 between 9:30 AM and 4:30 PM, totaling 1350 instances. We also tracked the pedestrian traffic within our school's fourth-floor plaza on October 29, between 9:30 AM and 3:05 PM, totaling 8100 instances. The counts were conducted via video recording and is accurate to the nearest 50 counts. This shows that there is high pedestrian traffic even at our

Figure 2: Method of counting pedestrian traffic at our school.

school, with about 400 students and 80 teachers in the secondary section.

Given Hong Kong's high population density of 6,801 people per square kilometer, footfall is a very constant and abundant energy source in Hong Kong, more so than the fluctuating weather conditions which solar and wind energy depend on. Therefore, piezoelectric energy could be a potential solution to reduce Hong Kong's reliance on non-renewable energy and lower energy costs. While its energy output is indeed modest, it could still power low-energy devices such as LED lighting and Internet of things (IoT) devices, contributing to the overall energy efficiency in an urban environment.

In this investigation, we made piezoelectric generators from piezoelectric buzzers, which can be purchased easily and frequently found in e-waste. In a piezoelectric buzzer, alternating current is applied to a piezoelectric ceramic, causing it to vibrate and produce sound waves. We used the piezoelectric buzzers in reverse; instead of applying an electrical signal to produce sound, mechanical stress is applied to the piezoelectric ceramic material in the buzzer, causing the material to deform and generate an electric charge across its surfaces.

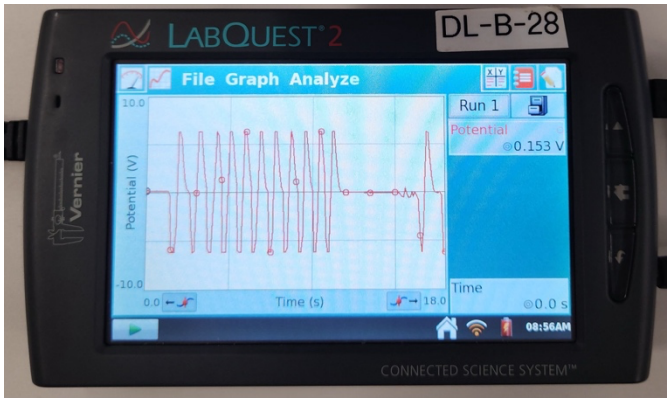

Figure 3: Voltage over Time graph showing the A.C. characteristics of the piezoelectric buzzer.

The outcomes of this study would be beneficial; by making use of a clean source of energy that would otherwise be wasted, Hong Kong can move one step closer towards achieving its sustainability goals. Economically, this can lead to savings on energy bills and reduce demand on municipal power grids and fossil fuels, especially during peak usage times.

Conducting the Experiment

Materials and Equipment Used

- Piezoelectric buzzers
- Recycled hard cardboard
- Electrical wiring
- Eight 1N5822 diodes
- Resistor of 1, 1.5 and 2 ohms.
- Glue gun and glue
- Soldering iron and solder

- Multimeter
- Vernier® LabQuest® 2 data logger and LabQuest® Differential Voltage Probe
- Video camera

Safety Precautions

- When soldering…
  - Wear safety glasses, heat-resistant gloves, and a mask to guard against fumes, burns, and accidental splashes of molten solder.
  - Work in a well-ventilated area or use a fume extractor to avoid inhaling potentially harmful fumes from soldering.
- When conducting the experiment…
  - Place visible signs around the testing area to alert people to the experiment and direct foot traffic accordingly.
  - Ensure the generator's surface is non-slip to prevent accidents as people step on it.

Privacy Precautions

- When conducting video data collection, we ensure that clear, visible labels are placed near the camera to inform passersby of the recording's purpose for research and data collection only, with details on privacy considerations. These labels communicate that the footage is collected solely to count foot traffic as part of our project and assure that individual identities are neither analyzed nor disclosed. We strictly adhere to privacy protocols by securely storing the video during collection and deleting all recordings immediately upon completing data analysis, ensuring data security and respecting privacy rights throughout the process.

Method

1. We prepared the aforementioned materials and equipment. The cardboard used in the generator is recycled.
   As part of our sustainability efforts 95% of this device is recycled, determined by mass.
2. We cut the piece of hard cardboard into suitable dimensions: 32.8 cm by 42.5 cm.
3. We glued the piezoelectric buzzers to the cardboard.

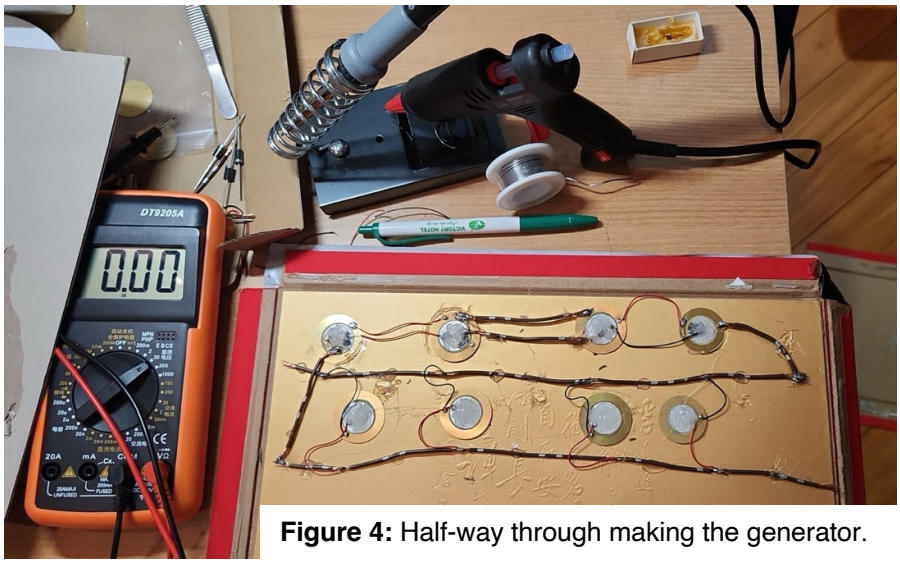

Figure 4: Half-way through making the generator.

4. We soldered the wirings to the buzzers.
5. By connecting four diodes in a closed-loop configuration, we made a full bridge rectifier to convert the buzzers' A.C. output to pulsed D.C. output.
   This was done later in the experiment when we found out that the generators produced an A.C. output.
6. We brought the completed piezoelectric generator prototype to school and installed it with the data logger on the floor of a frequented corridor.

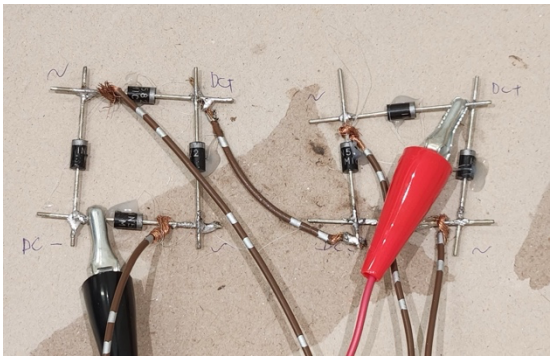

Figure 5: Our full bridge rectifier.

Figure 6: Energy harvesting device installed on the floor.

7. We set up a camera to monitor the number of passersby.

To further validate the efficiency of our generators, we conducted an efficiency test.

A person weighing 60 kilograms fall onto the generator from a height of 6 centimeters. To ensure accurate results, the test was conducted 15 times and with the average results calculated.

Energy consumed:

$$\text{Gravitational Potential Energy} = \text{mgh}$$

$$= 60 \times 9.8 \times 0.06$$

$$= 35.28 \text{ J}$$

Energy generated:

$$\text{Average voltage} = 7.9 \text{ V, Load} = 2.5 \ \Omega, \text{ Average contact time} = 0.26 \text{ s}$$

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

$$= \frac{7.9}{2.5} = 3.16 \text{ A}$$

$$\text{Power} = \text{Current} \times \text{Voltage}$$

$$= 3.16 \times 7.9 = 25.0 \text{ W}$$

$$\text{Energy generated} = \text{Power} \times \text{Time}$$

$$= 25.0 \times 0.26 = 6.5 \text{ J}$$

$$\text{Efficiency} = \frac{\text{Amount of energy generated}}{\text{Amount of energy consumed}} \times 100\%$$

$$= \frac{6.5}{35.28} \times 100\% = 18.42\% \text{ (3 s.f.)}$$

Results

We are unable to provide the raw data collected due to very large amounts of data produced by the data logger (30 samples per second).

Table 1: Shows the results from our experiment

Day 1: Monday Oct 28		
Number of Steps Counted	Total Energy Generated (Joules)	Average Energy Generated Per Step (Joules)
655	3597.5	5.5
Day 2: Tuesday Oct 29		
981	5005	5.1

The experiment was successful in generating measurable energy from footfall, with average energy generation per step being approximately 5.3 J across two days. The generator's efficiency was calculated as 18.42%, meaning that a significant portion of the potential energy exerted from each step was converted into electrical energy. This demonstrates that, while the efficiency is modest, piezoelectric footfall generators can contribute to energy needs in high-traffic areas, particularly for low-power applications.

Conclusion

Piezoelectric generators have the potential to serve as supplementary power sources in densely populated urban settings, especially in environments with a constant foot traffic like schools or public transit stations. By capturing otherwise wasted energy, this technology could play a role in reducing dependence on traditional energy sources and advancing sustainability goals, albeit with current limitations in energy yield.

Given the compact size of the board used in our piezoelectric generator—only 32.8 cm by 42.5 cm — the energy generated is limited but suitable for low-power devices. In real-world applications, the energy from multiple such generators could potentially be scaled up to power a variety of electric devices, including high-efficiency LED lighting, sensor networks, and Internet of Things (IoT) devices. Importantly, the energy we captured in this setup would otherwise be entirely wasted; each footfall, while modest in individual energy, cumulatively represents a significant untapped source of power.

In densely populated areas like Hong Kong, where foot traffic is consistently high, piezoelectric generators can play a valuable role by collecting this overlooked source of kinetic energy. By transforming footfalls into usable electricity, these generators could help reduce reliance on fossil fuels, support sustainable energy efforts, and decrease the strain on municipal power grids during peak hours. This approach not only aligns with

sustainability goals but also exemplifies an innovative use of existing energy flows in urban environments.

Reflection on Teamwork

Throughout this project, teamwork played a vital role in achieving our objectives. Each member brought unique skills and perspectives to the table, which allowed us to divide tasks efficiently and tackle challenges from multiple angles.

One challenge that we encountered was the assembling of the generator. It was difficult for us to coordinate the individual making of different components of the generator, as they must be put together and connected precisely. To resolve this, we held team discussions in school almost daily throughout the investigation process and met up after school as well, in order to troubleshoot technical issues with the piezoelectric components and circuitry and ensure better collaboration and coordination.

Working together also helped us build resilience and adaptability. When faced with unexpected results or setbacks, we could brainstorm and refine our approach as a team rather than working individually. This collaboration not only improved the quality of our work but also strengthened our problem-solving skills and trust in each other's capabilities. In future projects, we'll carry forward the communication skills, mutual support, and shared responsibility that were key to our success in this experiment.

Possible Sources of Error

1. The multimeter and data logger readings might have minor inaccuracies due to external interference, such as electromagnetic interference (EMI) and wireless interference, or equipment calibration issues.
2. Variations in the pressure and angle of footfall may affect energy output readings.
3. Fluctuations in temperature and humidity could impact the piezoelectric material's performance.

Areas of Improvement

1. Experimenting with different piezoelectric materials, possibly with higher sensitivity or more efficient energy conversion rates, could enhance performance. Examples include lead zirconate titanite and barium titanite. We could also use mechanical structures and employ regular motors for even higher efficiency and energy output.

2. Improving the rectifier circuit to reduce energy loss could increase overall output. Furthermore, capacitors can be used to smooth the output current.
3. Refining the physical design to ensure even pressure distribution across the piezoelectric modules may yield more consistent results.
4. Employing automated counters and more precise data logging systems could improve measurement accuracy and reduce human error.

Investigation Timeline

Week 1: We prepared most necessary materials and apparatus. We drafted a rough outline of the report.

Week 2: We drafted the design of the piezoelectric generator and a step-by-step process of making it.

Week 3: We made the prototype, also borrowing some equipment from the school laboratories.

Week 4: We brought the prototype to the school and underwent real-life testing and experiments. In two days (October 28 and October 29), we completed our experiment and data collection.

Week 5: Using data collected, we completed the report and presented our investigation to the schoolteachers (October 30).

Works Cited

Goal 7 | Department of Economic and Social Affairs. (n.d.). https://sdgs.un.org/goals/goal7

Ng, Y., & Ng, Y. (2017, July 14). Global study on walking puts Hong Kong a step ahead. *South China Morning Post*. https://www.scmp.com/news/hong-kong/health-environment/article/2102715/global-study-walking-puts-hong-kong-step-ahead

Table 915-91201 : Monthly statistics on consumption of electricity and gas by type of users. (2024, September 30). Census and Statistics Department gov.hk. Retrieved October 28, 2024, from https://www.censtatd.gov.hk/en/web_table.html?id=127

Hong Kong - The World Factbook. (2024, October 15). CIA the World Factbook. Retrieved October 29, 2024, from https://www.cia.gov/the-world-factbook/countries/hong-kong/